ALTERNATIVE EARTHEN FINAL COVERS FOR INDUSTRIAL AND HAZARDOUS WASTE TRENCHES IN SOUTHWEST IDAHO

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ABSTRACT

The Envirosafe Services of Idaho, Inc. (ESII) Site B facility in southwest Idaho is a former Titan Missile Complex operated by the Air Force. Currently, it operates as a storage, treatment, and disposal facility with on-site landfilling of industrial and hazardous (Resource Conservation and Recovery Act (RCRA) Subtitle C) wastes. The Idaho Department of Environmental Quality (IDEQ) is reviewing the construction option for an earthen final cover on a RCRA landfill at the facility. The earthen final cover, which takes advantage of soil moisture storage and evapotranspiration, is an alternative to EPA's standard composite final cover for RCRA C landfills. While research and demonstrations on similar covers are underway throughout the US, the alternative cover at ESII Site B will be the first in Idaho to be constructed as part of closure of a RCRA C landfill. Conditional approval of the alternative cover by IDEQ required a detailed, site-specific investigation of available borrow soils and climate data, and performance modeling of the alternative cover and comparison with the standard RCRA C cover. A permit application was prepared that included not only the investigation and performance modeling results, but also design drawings, details, and technical specifications for the final alternative covers. An instrumented test pad to monitor cover performance will be constructed simultaneously with the landfill cover. The final approval of the landfill cap will be conditioned to the successful performance of the cover design as determined by the test pad evaluation.

BACKGROUND

The Envirosafe Services of Idaho, Inc. (ESII) Site B facility in southwest Idaho is a former Titan Missile Complex operated by the Air Force. Currently, the facility provides storage, treatment, and disposal at an on-site landfill(s) of industrial and hazardous wastes. ESII serves several types of industries, including chemical, manufacturing, steel, petroleum, and pharmaceutical. Furthermore, some hazardous wastes are generated on-site from various site activities, including leachate generated from landfills, liquids collected from containment areas/systems, and other waste streams generated during the operation of on-site waste management units.

Figure 1 is a plan of the ESII Site B facility in southwest Idaho. The active disposal portion of the facility includes three active landfill disposal cells, designated as Cell 14, Cell 5, and Trench 11, and four surface impoundment disposal units, designated as Evaporation Pond No. 1 and Collection Pond Nos. 1, 2, and 3. Additionally, there is a landfill disposal unit, Trench 10, which has been partially closed by placing an intermediate soil cover over the wastes.

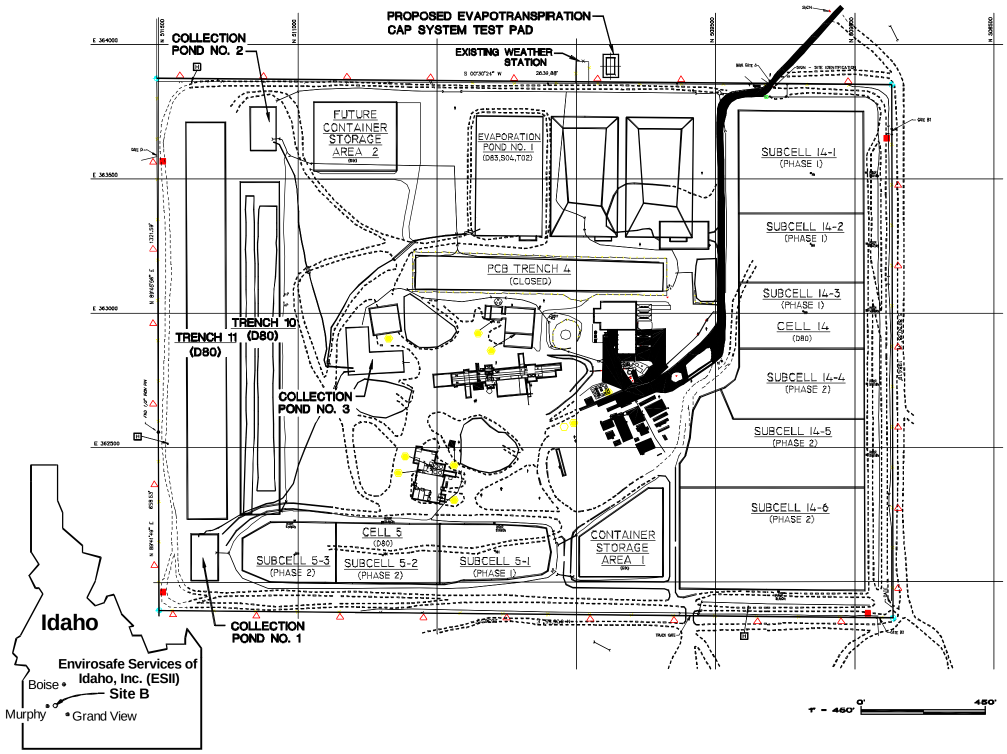

Figure 1. Location of ESII Site B in Idaho

Trenches 10 and 11 were the focus of this investigation. Both were originally excavated into undisturbed soils and are unlined.

As part of a Class 3 Permit Modification and Temporary Authorization Request (ESII, 1999), ESII has requested the use of alternative earthen final covers over Trenches 10 and 11. The alternative final covers would be constructed in lieu of standard composite final covers as recommended by the U.S. Environmental Protection Agency (EPA, 1989) for (RCRA) Subtitle C landfills. The IDEQ has reviewed the construction option, and has granted conditional approval pending successful performance of the design as determined from evaluation of a test pad to be constructed concurrently with the alternative final covers. The full-scale alternative final cover for Trenches 10 and 11 and test pad will be constructed at ESII Site B during the year 2000 construction season.

REGULATORY OVERVIEW OF RCRA C COVERS

Under Subtitle C of RCRA, the EPA has established a program to ensure that hazardous wastes are handled safely from generation until final disposition. Applicable State of Idaho and Federal regulations for treatment, storage, and disposal facilities, and established performance standards for hazardous waste landfills, surface impoundments, land treatment units, and waste piles are published in IDAPA 16.01.05.008 and 16.01.05.009 (Title 40 Code of Federal Regulations [CFR] Part 264 and 265). Specifically, 40 CFR 264.310 Subpart G establishes the closure requirements for such permitted facilities, and 40 CFR 264 Subpart N includes requirements for hazardous waste landfills.

Most applicable to this investigation are the regulatory requirements (40 CFR 264.310) for the design and performance of a final cover system, and the need for the final cover to limit infiltration into the underlying wastes such that liquids do not accumulate in the bottom of the waste cell following final closure. This accumulation of liquids is referred to as "bathtubbing" (EPA, 1989).

The EPA (1989) has recommended a cover design for hazardous waste landfills under Subtitle C. This "standard" cover includes, among other components, a flexible membrane liner (FML) underlain by a low-permeability soil layer. As such, the standard RCRA Subtitle C cover (herein referred to as the RCRA C cover) incorporates a low-permeability, resistive-type barrier to physically impede the downward movement of moisture from precipitation into the underlying wastes. Other applicable design recommendations for the RCRA C cover include, from the top (EPA, 1989):

- A surface soil layer (1) designed to minimize erosion and promote drainage; (2) with a uniform surface slope of 3 to 5 percent; (3) of adequate thickness such that the underlying low permeability layer is beneath the frost depth
- A drainage layer
- Optional layers as required to (1) control and remove gasses in the underlying wastes and (2) protect the cover from intrusion by burrowing animals.

The EPA (1989) recommends that the design of the final cover consider the specific conditions of the site. Further, the EPA recognizes that alternative designs to the standard cover may be applicable. Such designs may consider fewer or optional layers, as needed, to meet the mandated requirements of the final cover system. In any case, EPA recognizes the need to limit infiltration into the underlying waste as the prime element of the final cover, and any alternative design must provide long-term performance at least equivalent to the RCRA C cover.

SUMMARY OF ALTERNATIVE COVER TECHNOLOGY

A brief summary of the evapotranspiration (ET) alternative soil cover system for use in arid and semiarid climates is presented in this section. Also, the traditional RCRA C compacted clay cover is discussed relative to its application in these dry climates.

Standard RCRA Subtitle C Cover

Traditional landfill cover designs presently in use for RCRA Subtitle C (and D) regulated facilities and recommended by the EPA are used throughout the United States with little regard for regional conditions. Figure 2(a) illustrates the standard RCRA C cover as recommended by EPA (1989), and Figures 2(b) and 2(c) illustrate the RCRA C covers included in the ESII Permit Renewal Application (ESII, 1998) prior to consideration of an alternative earthen cover. Both Figures 2(b) and 2(c) illustrate covers that are slight modifications of the standard cover.

Experience (Mulder et al, 1995) in drier portions of the western United States has shown these designs to be vulnerable to desiccation cracking when installed in arid environments. Desiccation, which can occur by several mechanisms, is an important failure mode for compacted soil hydraulic barriers, especially in arid environments (Suter et al, 1993). The compacted clay barrier is typically placed with a relatively high volumetric water content. After installation, this layer will dry out in response to the dry climate, and the resultant volumetric moisture content will be much lower. This decrease in volume through drying leads to cracking of the compacted clay. The basic soil cover used with RCRA Subtitle D covers has a barrier layer that is also subject to desiccation cracking and other problems, such as deterioration due to freeze/thaw cycles.

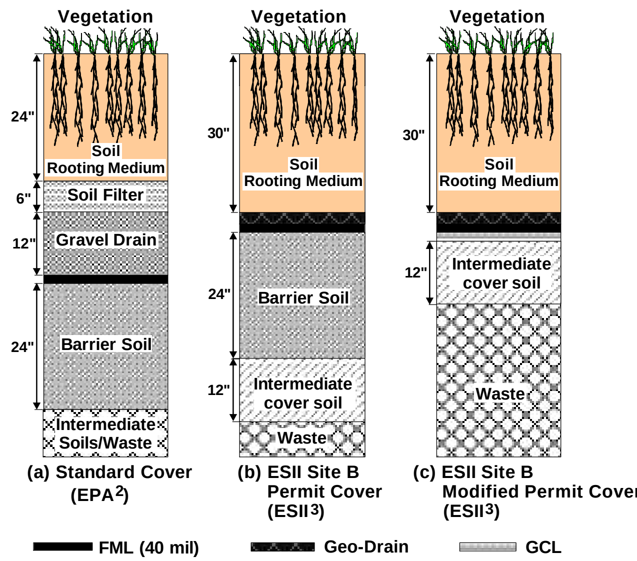

Figure 2. RCRA Subtitle C Covers

A serious shortcoming of traditional design methodologies is that they are generally concerned only with initial conditions. For example, the ability of the barrier layers to limit percolation may change with time. Conventional engineering approaches for designing landfill covers often fail to fully consider ecological processes. Natural ecosystems effective at capturing or redistributing materials in the environment have evolved over millions of years. Consequently, when contaminants are introduced into the environment, ecosystem processes begin to influence the distribution and transport of these materials, just as they influence the distribution and transport of nutrients that occur naturally (Hakonson et al, 1992). As the dynamic ecosystem of the cover changes, so will performance factors such as water infiltration, water retention, ET, soil erosion, gas diffusion, and biointrusion. The objective in constructing an effective landfill is to design the cover so that subsequent ecological change will enhance and preserve the encapsulating system.

Traditionally used RCRA covers employ a resistive-barrier type design. In this design, a barrier layer with a low saturated hydraulic conductivity is used to provide the primary resistance to downward flow. This barrier layer may consist of a geomembrane, a geosynthetic clay liner (GCL), a compacted clay (fine-grained soil) layer, or a combination of these materials. The high cost of traditional cover designs when compared with alternative cover counterparts (Dwyer, 1997) coupled with their limited success (particularly in arid or semiarid environments) lead to the emergence of permit applications for final closures with alternative cover systems. These alternative cover systems may be used in lieu of the traditional resistive-barrier system or in conjunction with one.

ET Alternative Cover

The typical ET cover (Figure 3) consists of a single, vegetated soil layer constructed to represent an optimum mix of soil texture, soil thickness, and vegetation cover (Dwyer, 1997). The ET cover is a very simple concept. It is basically a monolithic soil cover that employs a thick layer of soil with adequate soil-water storage capacity to retain any infiltrated water until it can be removed through ET. ET is the combination of direct evaporation from the soil combined with transpiration through vegetation. Transpiration is the process of water consumption by vegetation through root uptake, while evaporation is water consumption from the soil, water surfaces, and surfaces of the vegetation. The combined effects of evaporation and transpiration are key to performance of an ET cover.

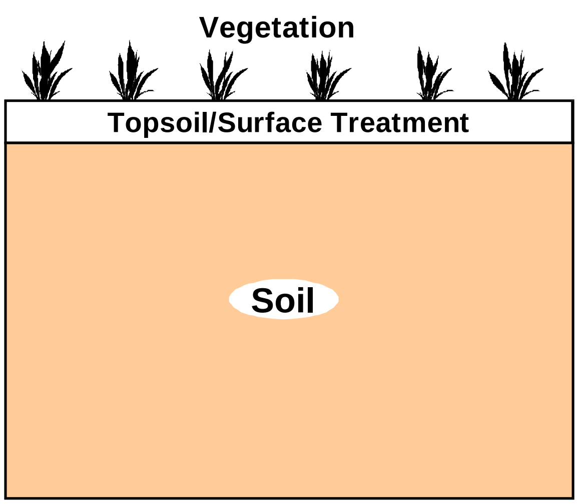

Figure 3. Typical ET Cover

The ET cover concept relies on the soil to act like a sponge. A key to the design is that the “soil sponge” or “soil rooting medium” be designed thick enough to hold infiltration of precipitation until the water can be consumed by evaporation. The soil used for an ET cover will generally come from a nearby borrow site; consequently, this cover is economical only where nearby soils are adequate. Studies (Nyhan et al, 1986; Nyhan et al., 1990; Hauser et al., 1994; and Dwyer, 1998) have shown that a simple soil cover can be very effective at minimizing percolation and erosion, particularly in arid or semiarid environments.

To determine the depth of soil required in an ET cover system, an estimate of the soil water storage capacity of the soil is required. The effective water-holding capacity of a soil is the difference between the field capacity and the wilting point of the soil. An estimate of soil water-holding capacity is typically provided in soil surveys. Field capacity is the amount of water a soil holds after several days of free drainage in the field. This parameter is typically estimated in the laboratory by draining a saturated soil sample to –1/3 bar water potential. The wilting point is the soil-water content at the soil-water potential where a particular plant species either wilts (typical of crop plants) or becomes dormant (Ritchie, 1981). This value is typically about 15 bars for crops and 25 to 30 bars for prairie grasses. This water storage capacity depends primarily on the soil’s texture and density. Water storage capacity is best determined at or near the in situ density of the surrounding site soils because this will be the natural equilibrium density of the vegetated soil.

Water-holding capacity of the cover soil must be adequate to store winter precipitation when evaporation and transpiration are at a minimum. The depth of soil used to meet this standard depends upon soil-water holding capacity. Local soil and climatic conditions must be assessed to determine this depth.

The ultimate goal of a designer is to design a maintenance-free landfill cover. Some time may pass before the ET cover reaches a state of equilibrium with its inherent environment. The cover should be stabilized with vegetation comprising plant communities that closely emulate a selected local “climax” (Reith and Caldwell, 1993). A “climax” community, in ecological terms is the type of plant community found in an area that has long been undisturbed and is in equilibrium with all other environmental parameters (e.g., climate, soil, landscape properties, fauna, and other flora). Central to the concept of “climax” is the community’s relative stability in the existing environment (Whittaker, 1975). A diverse mixture of native plants on the cover will maximize water removal through ET (Link et al, 1994). The cover will then be more resilient to natural and man-induced catastrophes and fluctuations in environments. Similarly, biological diversity in cover vegetation will be important to community stability and resilience, given variable and unpredictable changes in the environment resulting from pest outbreaks, and climatic fluctuations. Local native species that have been selected over thousands of years are best adapted to disturbances and climatic changes (Waugh, 1994). In contrast, plantings of non-native species common on waste sites are genetically and structurally monotonous (Harper, 1987) and are therefore more vulnerable to disturbances. Pedogenic processes will gradually change the physical and hydraulic properties of earthen material used to construct covers (Hillel, 1980). Plant communities inhabiting the cover will also change in response to these changes in soil properties.

Generally, vegetation is a key element in the design of the ET cover system; however, in very dry areas where the evaporation is far above the precipitation, vegetation may not be required. In these types of dry environments, a surface gravel veneer (Reith and Caldwell, 1993) or gravel admixture (Waugh, 1994) can be used to minimize erosion. The addition of a surface gravel veneer can actually encourage vegetation. This gravel veneer is only a few inches on the surface of the cover. This growth in turn increases the transpiration capacity available to remove moisture and prevent drainage after a desert deluge. This layer has several advantages in very dry climates:

- Reduce surface erosion due to both water runoff and wind erosion.
- Hold seed in place until it can germinate.
- Hold moisture in the uppermost layer of soil allowing vegetation such as native grasses to be established.

The difference between this gravel veneer and a rock or riprap covering is that the moisture is retained in soil near the surface, apart from the waste, where water-seeking roots will not damage the cell. Disadvantages include the reduced evaporation rate. This reduced evaporation may be a large enough factor to disallow the use of a surface gravel veneer. There is no hard evidence revealing whether the added vegetation that results from the gravel and the additional transpiration that ensues will outweigh the reduced evaporation. This decision is site-specific.

A surface gravel layer is often better than a gravel admixture. A gravel admixture can be used in combination with vegetation. Erosion and water balance studies (Waugh, 1994) suggest that moderate amounts of gravel mixed into the cover topsoil will control both water and wind erosion and have little effect on vegetation or soil-water balance. As wind and water pass over the surface, some winnowing of fines from the admixture is expected, leaving a vegetated erosion-resistant pavement.

LOCATION AND CLIMATE OF ESII SITE B

The ESII Site B facility is located at the end of Missile Base Road, approximately 10.5 miles west of the town of Grand View, Owyhee County, in southwest Idaho (Figure 1).

The site lies atop a broad ridge between the Snake River (located roughly 3.5 miles to the east) and an unnamed drainage swale to the west. Site topography is gently rolling, and the general slope is approximately 165 feet per mile to the east-northeast. The area is vegetated by shrubs and grasses.

The regional climate is semiarid with little annual precipitation. The average annual precipitation in Grand View during the period 1933 through 1998 is approximately 5.5 inches. The highest annual total during this period was slightly greater than 12 inches.

INVESTIGATION METHODOLOGY

Existing site soils and climate data were compiled and reviewed to formulate a preliminary opinion regarding the suitability of an alternative earthen cover for the ESII Site B. Limited geologic, hydrologic, and soils data were available from previous regional studies and on-site investigations. Climate data, including precipitation, air temperature, dew point, wind speed, and cloud cover were retrieved from the National Climate Data Center (NCDC) for both Boise and Grand View, Idaho.

The existing data were used as input to the infiltration models Hydrologic Evaluation of Landfill Performance (HELP) (Schroeder et al, 1994) and UNSAT-H (Fayer and Jones, 1990). The models were used to assess the preliminary infiltration performance of various alternative earthen cover scenarios relative to the infiltration performance of the standard RCRA C cover as illustrated in Figures 2(b) and 2(c). The preliminary modeling indicated that an alternative cover would perform as good as, or better than, a standard RCRA C cover. Also based upon the preliminary modeling, a decision was made to pursue the design of an ET alternative cover for Trenches 10 and 11.

The following sections describe a field investigation for collection of specific site data to support the design; assessment of the performance of an alternative ET cover; specifications for the recommended alternative ET cover components; and a cover monitoring program plan to evaluate the performance of the constructed cover.

FIELD INVESTIGATION

According to the Soil Conservation Service (SCS) soil survey for Owyhee county, Idaho (SCS, 1991), soils at and peripheral to the ESII Site B are predominantly wind-deposited fine sandy loam (loess) overlying coarse-grained deposits of the Snake River. In addition, silty clay-loam lake sediment deposits are also within the site area. Also according to the SCS (1991), characteristic vegetation for the soil types described above includes Wyoming big sagebrush, black greasewood, basin wild rye, Indian ricegrass, Thurber needlegrass, and other perennial grasses and shrubs in lesser amounts.

A field investigation was conducted in mid-November 1998 to obtain site-specific information for detailed design and performance assessment of the alternative ET cover. The following sections describe the sampling activities, observations made regarding the site soils and vegetation, and the laboratory analyses conducted on the soil samples that were collected.

Sample Collection

Fourteen test pits were dug within the ESII site boundaries to characterize borrow material for construction of an ET alternative cover. All of the test pits were excavated using a tire-mounted backhoe, with the exception of two which were dug with hand shovels. The two samples taken with hand shovels were from the existing (intermediate) soil cover over Trench 10 to determine the suitability of those soils for use in the ET cover.

The majority of the test pits were excavated in natural terrain on ESII property. All test pits were surveyed and mapped for location to replicate the subsurface soils for future borrow construction of the alternative cover. The depths of the test pits generally ranged from 5 to 8 feet. The soil profile generally consisted of 1 to 3 feet of loess overlying coarser Snake River deposits. Visual inspection of the test pits indicated that the underlying material (Snake River sediments) was too coarse to provide adequate water-holding capacity for construction of the soil rooting medium of an ET cover. However, a sample of the material was collected to analyze grain size and to quantify water-holding capacity and other hydraulic properties because the coarse sediments are potentially useful for erosion protection of the ET cover. The overlying loess materials, which were sampled for laboratory testing, appeared suitable for soil rooting medium for a final cover.

In most of the test pits, calcium carbonate in the loess increased noticeably at approximately 1 foot depth. Most of the carbonate in the profile was observed between 1.5 and 3 feet, and the carbonate typically extended about 2 feet into underlying gravel. The local soils are carbonate rich, and natural rainfall is undersaturated with respect to calcium carbonate. Therefore, rain dissolves near-surface carbonates and moves them deeper in the profile. In humid climates, carbonate is eventually leached out of the profile. In arid and semiarid climates, plant roots extract water from soil pore water that is saturated with calcium carbonate deeper in the profile. This leads to precipitation of carbonate. The depth at which carbonate accumulation starts and stops is dependent upon texture in a dry climate. In coarser topsoils, carbonate is leached more deeply before plant roots recapture the water. In coarser subsoils, carbonate is often observed to greater depths and with more variable accumulation due to the low and variable water-holding capacity. Based upon these observations in the test pits, the loess material, if 3 feet thick or greater, has adequate water-holding capacity to limit deep percolation of rainfall.

Observations made during sample collection indicate that site vegetation is dominated by annuals, including cheat grass, kochia, and Russian thistle. The test pits showed these annuals to be shallow rooted, with most of the roots in the top foot of soil. Several test pits, however, were dug near sage. These pits showed that living roots were fully colonizing the soil profiles to the full depth of trenching. In addition, copious dead roots were observed under locations dominated by annual plants. The morphology of the dead roots suggests these are primarily sage roots. Root observations are considered important because plant transpiration plays a key role in an effectively functioning vegetative cover. Soil-water potential samples were collected in both an annual-dominated test pit (TP-4) and in a sage-dominated test pit (TP-5) to try to quantify the ability of plant roots to extract water from the soil profile. The following section presents these calculated soil water potentials, as well as a summary of the other laboratory analyses.

Laboratory Analyses

Laboratory testing of selected samples from the test pits included proctor compaction, Atterberg limits, particle size distributions, hydraulic conductivities (saturated and unsaturated), bulk densities, initial soil water potential, and moisture characteristic curves.

In summary, the loess soil tested for use as potential borrow material classifies as sandy loam according to the USDA classification and as sandy silt (ML) according to American Society of Testing and Materials (ASTM) standards. The in situ saturated hydraulic conductivities for this material are in the 10^{-4} to 10^{-5} cm/s range with water holding capacities of approximately 15 percent. In situ water potentials were mostly in the –20- to –30-bar range (typical of dry rangeland). The underlying coarse sediment was classified as silty sand with gravel (GM). Unsaturated properties of materials tested appear externally consistent with general soil survey information (SCS, 1991) and internally consistent with measured hydraulic conductivities and soil textures.

Figure 4 illustrates the calculated soil water potentials for samples collected from two of the test pits (TP-4 and TP-5). Soil-water potential is an indication of the relative dryness of the soil, and is a measurement of the soil matrix "tension" or "suction" in bars. The dryer the soil, the higher the relative tension or potential.

In general, the soil-water potentials illustrated in Figure 4 are very low. The near-surface samples (0.5-foot depth) from both test pits were collected from below the surface. The samples, which were wet from recent precipitation, were of very low potential (–34 and –42 bars for test pits TP-5 and TP-4, respectively), showing evidence of surface evaporation. Below near-surface, the soil-water potentials are different for TP-4 and TP-5.

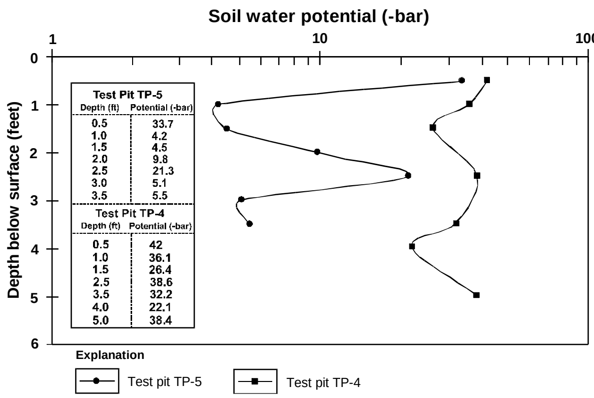

Figure 4. Soil Water Potential Profile

The deeper samples from TP-4 generally vary between potentials of –20 and –40 bars, while samples from TP-5 generally vary between –4 and –10 bars. The soil profile is also different. The soil profile at TP-4 is loess from ground surface to 18 inches depth, then coarse sediments below, while there is no loess at TP-5, only coarse sediments. These results suggest:

- The annual vegetation has maintained the maximum water-holding capacity of the soil through mid-November when the samples were collected.

- The traditional definition of soil-water holding capacity, that is, the water content difference between –0.3 and –15 bars, is underestimated at the ESII Site B, where the vegetation is capable of depleting soil water to well below –30 bars.

- The soil profile at TP-4 is well suited for removing moisture and limiting deep percolation, and the soil profile at TP-5 is not as well suited to control percolation as shown by water potentials of approximately 5 bar. Virtually no loess was present in TP-5, and therefore the water-holding capacity of the soil profile is less in TP-5 than in TP-4.

- The soil water potential data from test pit TP-4 suggest that an alternative ET cover at the ESII Site B would perform very well and would be very effective in limiting deep percolation of precipitation.

SUMMARY OF WATER BALANCE MODELING

The preliminary modeling using both HELP and UNSAT-H was refined using data from the field investigation and laboratory analyses. This section summarizes the water balance modeling to help assess infiltration performance, as well as the assessment of overall performance of the proposed ET cover.

Based upon the review of available information about the site, water balance modeling, site inspection, sample collection, and laboratory analysis of selected samples, an alternative ET cover was proposed as illustrated in Figure 5. The cover consists of a 6-inch erosion protection layer; 42 inches of soil rooting medium; and 12 inches of intermediate soil cover. In addition, an animal intrusion barrier is included 12 inches below the surface of the cover. The details of each of these components is discussed later in this paper.

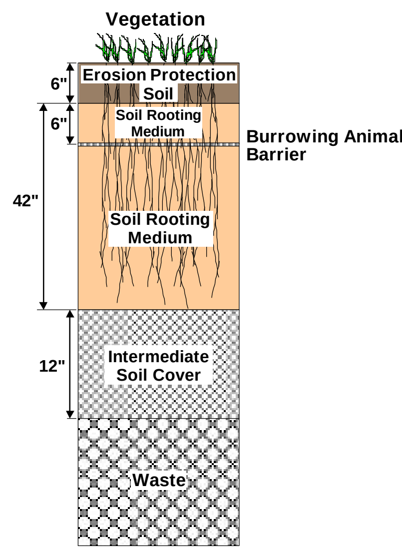

Figure 5. Proposed ET Cover, Trenches 10 and 11

The regulations (EPA, 1989) require that the alternative ET final cover provide long-term performance that is at least equivalent to that provided by the RCRA C final cover. In order to assess the infiltration performance of the ET alternative final cover, both the RCRA C cover and the proposed ET cover were modeled with both HELP and UNSAT-H to estimate percolation from each cover. Such analyses are commonly done using accepted computer models that help simulate cover performance under a range of input conditions. While the computer model assessment of water balance should not be used by itself regarding equivalence, it can be used in conjunction with other supporting evidence, including site observations, laboratory data, and other similar site applications of an ET soil cover.

The HELP and UNSAT-H models require slightly different input and in somewhat different formats. It is generally recognized that HELP tends to overestimate deep percolation, particularly for semiarid and arid climates (Peyton and Schroeder, 1988; Nichols, 1991; Thompson and Tyler, 1984). However, Stephens and Coons (1994) found HELP to accurately predict percolation at a semiarid site in southern New Mexico when compared to independent estimates of recharge using the chloride mass balance method and hydrogeologic properties.

For both models, an average annual precipitation of 10.76 inches was used, which is approximately two times the average annual amount for Grand View, Idaho. This value was selected as a conservative condition for cover performance evaluation to ensure the proposed ET cover will perform under extended "stressed" precipitation conditions.

The HELP model was used to simulate both the proposed ET cover (Figure 5) and the standard RCRA C cover (Figure 2(b)), each for a period of 30 years. UNSAT-H was used to simulate only the proposed ET cover for a period of 32 years. Table 1 summarizes the results of the water balance modeling.

Table 1. Summary of Water Balance Modeling, ESII Site B

Model	Period (yrs)	Precip Range[a]	Precip Mean[b]	Perc Range[c]	Perc Mean[d]
HELP RCRA C	30	6.97 – 14.65	10.57	2.4E-13 9.7E-13	8.1E-13
HELP ET	30	6.97 – 14.65	10.57	0 2.0E-09	1.3E-10
UNSAT-H ET	32	8.08 – 12.10	10.77	9.9E-13 9.9E-13	9.9E-13

[a]Range of precipitation (inches) during simulation period
[b]Arithmetic mean precipitation (inches) over simulation period
[c]Range of calculated percolation rate (cm/sec)
[d]Geometric mean of calculated percolation rate (cm/sec)

Simulated percolation from both covers is very small, indicating that nearly all of the precipitation that falls on the covers is lost to surface runoff, lateral drainage, or evapotranspiration rather than percolating through the cover. The modeling results indicate that the RCRA C and proposed ET covers are both very effective in limiting percolation. The following section presents a complete discussion of percolation, including the modeling results, in terms of equivalent performance for the RCRA C and ET covers.

ASSESSMENT OF ET COVER PERFORMANCE

This section addresses the performance of the proposed ET alternative cover for Trenches 10 and 11 (see Figure 5) at the ESII Site B. Specifically, control of percolation, erosion, animal intrusion, vegetation, and long-term build-up of free liquids in the base of the trenches are addressed in terms of cover performance.

Final covers, or caps, placed over waste for closure must serve several purposes. For this reason, covers or caps are often referred to as "cover systems." Rarely does a single component of a cover system influence the performance of the cover system in a simple, singular way. For example, the 6-inch erosion layer of the proposed ET cover (Figure 5) influences, at a minimum, both deep percolation of precipitation and erosion of the cover surface by wind and water. The only component of the proposed ET cover that has a singular affect on cover performance is the burrowing animal barrier (Figure 5).

The standard RCRA C cover illustrated in Figure 2 must meet the design standards (specifications) provided in the regulations and detailed in EPA (1989) guidance. Because the proposed ET cover works as a system to meet the mandated regulatory requirements of an alternative final cover, the components of the proposed ET cover are discussed in terms of performance in this section.

<u>Percolation</u>

EPA (1989) recognizes the need to limit percolation into the underlying waste of a waste repository as the prime element of the final cover. Any alternative design to the standard RCRA C cover must provide long-term performance at least equivalent to the standard design. This section focuses on equivalence of the proposed ET cover to the RCRA C cover in terms of percolation.

Previous experience suggests that defining percolation equivalency for an alternative cover can be somewhat involved and complex. In two recent projects, issues of experimental and numerical resolution have lead to the selection of an equivalency criterion of 1.3 mm/y (4 x 10^{-9} cm/s) for several Rocky Mountain Arsenal (RMA) alternative covers near Denver and 3.2 mm/y (10^{-8} cm/s) at Ft. Carson near Colorado Springs, Colorado. At RMA, both EPA Region 8 and Colorado Department of Health and Environment (CDHE) officials were involved in the selection and acceptance of the equivalency criterion. At Ft. Carson, only CDHE officials were involved with the selection of the criterion since a precedence was established with EPA at RMA. Both sites also used UNSAT-H for water balance calculations and as a cover design tool. With both sites as important and credible predecessors to defining equivalence relative to percolation rates calculated using water balance models, the modeling results provided in this paper indicate that the proposed ET cover is at least equivalent to the RCRA C cover in limiting percolation.

The proposed alternative ET cover for Trenches 10 and 11 consists of 5 feet (60 inches) of soil. This cover yielded percolation estimates of well under 1 mm/y for both HELP and UNSAT-H (see Table 1). As typically encountered, HELP is almost totally insensitive to cover thickness and is extremely sensitive to evaporative zone depth, which is primarily dependent upon rooting depth. Observed rooting depths in the test pits and rooting depths noted in the soil survey (SCS, 1991) are approximately 60 inches, that is, the full depth of the cover. For the UNSAT-H and HELP modeling, the rooting depth was assumed to be the entire depth of the soil cover (60 inches).

The following subsections provide additional supporting information to help demonstrate percolation equivalence of the ET cover to the RCRA C cover. The numerical calculations using HELP and UNSAT-H are discussed in greater detail relative to inherent limitations of the models in predicting percolation rates.

Field Observations: As described previously, test pits were dug by backhoe in potential borrow areas for soil sampling and for observation of soil profiles and root distributions. Surface soil textures were uniform throughout the borrow area, as is typical of wind-deposited sediments. Selected soil samples were collected by hand sampling from backhoe-opened trenches at intervals of approximately one foot, placed in labeled resealable plastic bags, and placed in 5-gallon containers for transportation and storage.

Calcium carbonate was present in the excavated test pits. Carbonate appeared to be leached to the greatest depth at test pit TP-5, where minimal loess was present and the water-holding capacity of the soil profile was less than other observed pits. Calcium carbonate accumulation is typically encountered in soils with little or no recharge.

Plant root profiles seen in the test pits at ESII Site B are qualitatively similar to rooting patterns observed in other arid and semi-arid grasslands. Rooting density is highest in the upper soil profile where most water uptake occurs and decreases rapidly with depth. Rooting density with depth is typically described and modeled as decreasing exponentially with depth. This description, for example, is incorporated into UNSAT-H and many other models performing ET calculations. Rooting patterns are a function of plant species, soil texture, and climate.

Reynolds and Fraley (1989) have studied rooting patterns in southern Idaho. Their observations were based upon the addition of a radioactive tracer (^{32}P as phosphate) at varying depths to directly determine the depth of uptake by various species. Big sagebrush (*Artemisia tridentata*) showed the deepest uptake at 225 cm. Roots of the grass Great Basin wild rye (*Leymus cinereus*) showed uptake at 200 cm. Other grass species showed a shallower maximum.

The proposed ET cover design thickness of 5 feet (Figure 5) is approximately equal to observed rooting depths at Idaho National Engineering and Environmental Laboratory (INEEL) and with locally observed rooting depths in the test pits. This is not a coincidence. A physically based numerical model with accurate soil, plant, and climate parameters will predict a depth at which little additional downward flux of water occurs. Grasses invest minimal energy in growing roots below a depth where significant water uptake can occur. As such, rooting depths for the proposed ET cover are not expected to extend below the cover depth of 5 feet.

Laboratory Data: Water potentials were measured using a laboratory Richards thermocouple psychrometer. The psychrometer measures the relative humidity of an air pocket in equilibrium with a small soil sample immediately beneath the air pocket.

Water potentials in the loess-covered soil profile are quite low. Figure 4 shows water potentials of approximately –20 bars in the vegetated profile. Water potential profiles are consistent with plant physiology literature concerning water removal by semiarid vegetation. Water is generally considered the limiting factor for plant growth in semiarid grasslands. In addition, these water potentials were obtained under a cover consisting primarily of the annuals kochia, cheatgrass, and Russian thistle. While existing vegetation appears adequate from a cover performance perspective, annuals and perennials, which are even more effective at transpiring soil moisture, will be used for the ET cover.

The soil water potential-unsaturated hydraulic conductivity data can also be used as a crude estimate of the water percolation rate. For example, a typical water potential-unsaturated hydraulic conductivity graph for the loess samples shows that the calculated hydraulic conductivity at -10 bars is 10^{-12} cm/s or 0.03 cm per 1000 years. The measured in situ potentials are even drier than -10 bars, which suggests an even lower percolation rate. However, distinguishing a value of 10^{-12} cm/s from either no percolation or from a percolation rate four orders of magnitude higher is beyond any currently plausible experimental verification. This estimate or even estimates of similar orders of magnitude based on more sophisticated estimating techniques (e.g., UNSAT-H) can be considered potentially misleading. Some of the key accuracy and precision issues are discussed below.

Limitations of Numerical Calculations: While HELP and UNSAT-H yield percolation results that are relatively consistent with each other, with field observations and laboratory data, the limitations of numerical approaches must be discussed. Percolation rates can be estimated by numerical models and/or measured in the field. As in all physical systems, numerical models and field demonstrations have accuracy limits. Both numerical models and field experiments have been used for this project and other projects to estimate percolation. Although UNSAT-H and HELP numerical modeling for the ESII Site B show that the proposed ET cover and RCRA C cover limit percolation to a fraction of a millimeter annually, these values are far less than the percolation criterion for RCRA equivalency of 10^{-8} cm/s (3.2 mm/y). For the reasons discussed previously, covers with a calculated percolation of less than or equal to 3.2 mm/y are considered to be RCRA equivalent.

These models are also based on experimental resolution and accuracy limits for the measurement of percolation through cover field demonstrations. For example, a limitation in field test accuracy is that thermally driven water flow limits the accuracy of the flux measurements. Seasonal temperature fluctuations drive waves of water vapor up and down through the soil profile. Estimates from Milly (1996) indicate that, at a depth of approximately one meter, the downward thermally driven water flux during the warm part of the year would be approximately 4 mm. Downward flux could be intercepted, collected, and measured in a lysimeter. In a natural system, the direction of the thermally driven flux reverses during the winter season, and mostly compensates for the downward summer flux. These effects are ignored in available models and most experimental work.

Gee and Hillel (1988) point out that numerical models of water balances (such as HELP and UNSAT-H) may not accurately estimate recharge in arid and semiarid zones where recharge may be only about one percent of annual precipitation. Of course, one source of this difficulty would be the limitations of the model's component algorithms. Additionally, accuracy of model predictions is limited by the accuracy of input soil, climate, and vegetation data. For example, even a fairly standard measurement such as precipitation can have significant error. Veissman et al. (1989) report that precipitation records have shown differences of 20 percent or more in rain gauges less than 20 feet apart. A subtler example of data input inaccuracy lies with leaf area index (LAI). In most models (including UNSAT-H), LAI is assumed to follow a prescribed seasonal pattern. This pattern is generally repeated for each simulated year. The models do not automatically account for the tendency of plants to green up (therefore increasing LAI) during wetter years. Transpiration is therefore likely to be underestimated (and percolation overestimated) in wet years.

Considering that the precipitation data set used for the HELP and UNSAT-H simulations is conservatively wet, the very low percolation rates calculated by the models may be overestimated.

No model considers all relevant physical processes contributing to the hydraulic performance of covers. UNSAT-H, for example, cannot simultaneously simulate both evapotranspiration and nonisothermal water vapor movement because it cannot correctly account for the latent heat of evaporation. Consequently, modeling of evapotranspiration with UNSAT-H (or any other isothermal model) introduces inaccuracy into simulation estimates of drainage from the covers. Other unmodeled processes affecting model accuracy include edge effects, small-scale soil heterogeneities, and interactions of rainfall and plant growth. For both UNSAT-H and HELP, top slopes of the cover in the range of 2 to 5 percent do not significantly affect calculated percolation. Calculated percolation rates for slopes steeper than 5 percent may decrease because of enhanced surface runoff from the steeper slopes.

Numerical errors can also contribute to inaccuracies. Numerical mass balance errors in individual UNSAT-H modeling runs of the proposed ET cover have been approximately 1 to 3 mm ($\sim 10^{-8}$ cm/s for 1-year simulations).

For these reasons, the value of 10^{-8} cm/s has been selected as a threshold value for the pass/fail criterion of either modeling or measurement of percolation. For a cover roughly one meter thick in the Boise area, any prediction or measurement less than 10^{-8} cm/s is essentially indistinguishable from no percolation.

Two research groups also have independent field observations and modeling results from alternative cover design tests in Idaho. Dr. Jay Anderson (1998) at Idaho State University and Indrick Porro (1998) at INEEL have been testing covers onsite at INEEL.

While Grand View and Idaho Falls are very similar, Idaho Falls is slightly cooler and wetter than Grand View and has a slightly larger fraction of spring and summer rains. Their published and ongoing results (Anderson, 1998; Porro, 1998) are very similar to the proposed ET cover design profile.

Control of Erosion and Animal Intrusion

Two primary components of the proposed ET cover (see Figure 5) control erosion and animal intrusion. Erosion is controlled by the erosion layer, and animal intrusion is controlled by the burrowing animal barrier, which are discussed in this section.

The texture of the surface materials, vegetation, and the geometry of the final cover primarily control erosion of the final cover by water and wind. For the proposed ET cover for Trenches 10 and 11, the coarse granular material selected for the upper 6 inches of the cover (see Figure 5) will work well to control erosion. The erosion protection layer for the proposed ET cover will consist of a 50/50 mix (by volume) of silty gravel with sand (GM) and wind-blown silty sand (loess, ML).

Calculations were done to assesses the suitability of the coarse Snake River deposits that underlie the wind-blown loess in the proposed borrow area immediately south of the ESII Site B for controlling erosion. The calculations show that these coarse deposits are suitable for protecting the cover from erosion as long as sideslope lengths and angles are limited. For a sideslope of 3:1 (horizontal to vertical), the maximum slope length was calculated to be approximately 64 feet. For a sideslope angle of 5:1, the maximum slope length was calculated to be approximately 270 feet.

The Snake River deposits proposed for use in the erosion layer are silty gravel with sand. The median particle diameter (d_{50}) of the erosion layer is 3.9 mm. Removal of the finer fraction of the erosion protection layer by wind (deflation) will selectively leave coarser material at the surface of the cover, which will effectively increase the median diameter of the particles. As such, any long-term erosion by wind will act to increase the cover's ability to resist erosion by water. Accumulation of gravel at the surface occurs naturally at the site, and a smaller mass fraction of gravel lies below the natural surface of the loessal soils. The Snake River gravel mixed in with the overlying and subsequently deposited loess was likely incorporated by bioturbation (burrowing and disturbance by animals) from the larger of the local rodent population. The relatively small amount of gravel observed in the loess and the lack of evidence of any burrows penetrating into the underlying coarse sediments at the test pits suggest that the rate of bioturbation is small. Bioturbation, however, can lead to increased rates of erosion, especially on graded surfaces typical of landfill covers.

While bioturbation rates appear low at the site, they are not negligible. A simple quantitative way to deal with the effects of burrowing and exposure of bare soil is to simply ignore the beneficial effects of vegetation on erosion rates. Bioturbation can also be reduced by installation of a barrier, which is a simple method of precluding burrowing. Mesh fencing is simply rolled out over the cover between lifts and covered with soil. Most animal-induced cover erosion is caused by the larger rodents (e.g., gophers, ground squirrels, and prairie dogs) and not by the smaller burrowing rodents (e.g., shrews, voles, and mice). To stop large- and medium-sized rodents, class 1 galvanized poultry fencing with 1-inch mesh and 1-foot overlap is proposed for the ET cover. This material is adequate because soils typical of the site are relatively coarse-textured, dry, and non-acidic.

Vegetation

Transpiration by a vegetative cover, in conjunction with evaporation, has been suggested as a simple and elegant method of virtually eliminating percolation through a properly designed cover with appropriate vegetation in the Snake River valley (Anderson, 1997).

Existing local vegetation consists primarily of cheatgrass, kochia, and Russian thistle. Because the cheatgrass biomass tends to accumulate and burn in this ecosystem, shrubs (e.g., sage and rabbitbrush) are often killed by fire. One small area on the proposed borrow site has charred shrubby material surrounded by annuals, and the phenomenon appears to be widespread in the area. The existing annual vegetation is undesirable from an ecological or ranching perspective. However, from the narrower perspective of a landfill cover, the growth of desert annuals is water limited, and water potential data suggest the annuals fully extract plant-available water, stabilize the soil surface, and provide adequate vegetation.

While annuals may perform adequately, a consensus exists among practitioners that perennials provide a more stable, long-term cover for both transpiration and erosion control. The grass mixture selected for use on the proposed ET cover was based upon local recommendations. The mixture consists of crested wheatgrass (*Agropyron desertorum*), Siberian wheatgrass (*Agropyron fragile*), and streambank wheatgrass (*Elymus lanceolatus).* Crested and Siberian wheatgrasses are introduced, and the streambank wheatgrass is native. Crested wheatgrass is often favored in seed mixes because of its vigor and ease of establishment. Although it is naturalized in the western United States, it is less favored for grazing because of its low palatability. For landfill covers, low palatability results in reduced grazing, foraging, and burrowing.

Accumulation of Free Liquids

If more liquid enters the closed trenches through the cover as percolation than leaves the trenches at the base of the waste, liquids may accumulate (bathtub) in the trenches after closure. To assess this condition for unlined Trenches 10 and 11 following final closure, infiltration of precipitation through the final ET cover was compared with the ability of the trench foundation soils to drain any liquids.

Calculations were done to assess the potential for bathtubbing after closure of Trenches 10 and 11. The calculations, which involved comparing the long-term moisture flux through the proposed ET cover to the conductivity of the underlying foundation materials, showed that the rate at which liquid enters the trenches through the ET cover is much lower than the potential of the foundation soils to drain any liquids. As such, there is no potential for bathtubbing in Trenches 10 and 11 following final closure with the proposed ET cover.

COVER MONITORING PROGRAM

As part of the ESII Class 3 Permit Modification Request (ESII, 1999), and in response to IDEQ comments, a Cover Monitoring Program Plan was written to present information for the proposed construction, instrumentation, and monitoring and sampling of a test pad to demonstrate performance of ET alternative final cover at the ESII Site B in Idaho. The plan also proposes pass/fail performance criteria to determine the suitability of the proposed alternative cover based on the monitoring and sampling described in the plan.

Because Trenches 10 and 11 at ESII Site B are unlined, the demonstration test pad will also be unlined. The ESII Site B demonstration will focus on bromide tracers and water potential profile analyses to evaluate performance. The test pad demonstration will be constructed adjacent to the ESII Site B weather monitoring station (see Figure 1) in a manner identical in both method and content to the proposed final covers for Trenches 10 and 11.

The proposed monitoring and sampling described in the plan will not only provide the data to determine the numerical threshold value described previously, but will also provide data that allows simple, qualitative assessment of the pass/fail performance of the test pad and proposed alternative cover.

Test Pad

The top surface of the test pad will be 60 feet long by 30 feet wide and will slope longitudinally to the east at 5 percent. The 5 percent final grade of the test pad design was chosen to mirror the performance of the crest of the full-scale ET caps to be constructed for Trenches 10 and 11, which have a maximum design slope of 5 percent. The 5 percent design slope for the crest of the landfill is consistent with EPA guidance, which recommends a 3 to 5 percent slope on landfill crest areas. All layers of the ET cap test pad (i.e., subgrade through final grade) will be constructed at a 5 percent longitudinal slope. This design will ensure that the monitoring of moisture potential within the ET cap test pad is maximized (i.e., conservative assumption based on using the maximum design slope for the crest of the landfill) under all climatological conditions that affect ESII's Site B, including stormwater runoff conditions, wind effects, and evapotranspiration processes. The overall footprint of the test pad will be 86 feet long by 56 feet wide at the perimeter of the side slope toe. The test pad generally follows the existing natural topography, which gently slopes to the east away from the site perimeter security fence. The side slopes of the test pad will slope at 3 (horizontal) to 1 (vertical) away from the top slope to existing grade. Positive drainage of water away from the toe of the side slopes will be promoted by minor site grading, as required, around the periphery of the pad, including the construction of three small drainage swales located on the north, south, and west perimeter of the test pad. The swales will prevent stormwater run-on to the test pad.

Instrumentation

The test pad will be equipped with instruments to measure and assess infiltration performance of the proposed alternative final cover as required to demonstrate equivalency with a standard RCRA C cover. It is not within the scope of this program to measure and assess any other components of the water budget, such as surface runoff or evapotranspiration, or any other parameters used in the numerical modeling of the ET cap, such as biomass, leaf area index, field capacity, or wilting point. This section describes the type of soils data to be collected to assess infiltration performance, the instruments to be installed in the test pad and their calibration, and the procedure for installing the thermocouple psychrometers.

> **Soils Data:** Soils data to be measured or monitored include laboratory measurement of unsaturated hydraulic properties of the cover components, monitoring of soil water content and potential, and monitoring of a bromide tracer in the soil profile.

Psychrometers: Water potentials are typically low (less than –3 bar) in arid and semiarid soils such as those found at the ESII Site B. At these potentials, tensiometers and suction lysimeters cannot work. In addition, unsaturated hydraulic conductivity changes rapidly with changes in water content as measured by instruments such as neutron probes and time domain reflectometry. At these water potentials, which are anticipated at the bottom of the proposed ET covers, thermocouple psychrometers are more sensitive in detecting both changes in the soil moisture characteristic curves and in the direction of water movement. Therefore, the high-sensitivity thermocouple psychrometers were chosen to monitor the soil profile.

Two nests of eight psychrometers will be installed in the test pad to measure soil water potential within the proposed final cover profile (Figure 6). The psychrometers shall be a PCT-55 thermocouple psychrometer, manufactured by Wescor, Inc., or an equivalent instrument approved by the Owner/Engineer. The psychrometers will be calibrated by an approved laboratory. Calibration is necessary to obtain quantitative data for calculation of soil water flux. The calibration will consist of a three-point calibration within the water potential range of –4 to –40 bar for each psychrometer.

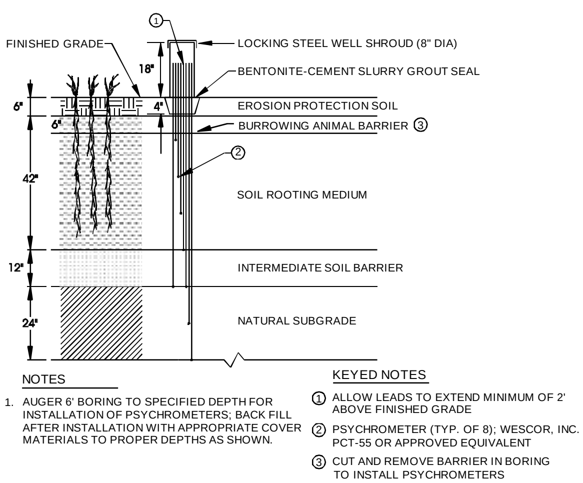

Figure 6. Nested Psychrometer Detail

Monitoring and Sampling

Performance data for the test pad will be obtained by monitoring the nested psychrometers and conducting limited laboratory testing of samples collected from the test pad. A sodium bromide tracer will also be used to provide a qualitative indicator of how far water moves into the test pad over the period of the demonstration, which is proposed to be 5 years, effective upon completion of the test pad construction. Table 2 summarizes the monitoring and sampling of the test pad.

Table 2. Test Pad Monitoring Plan Summary

Activity	Time of Activity	Purpose
Tracer application	Early spring, before greenup	Locate deepest movement of wetting front
Tracer sampling	Year 5, end of summer	Locate deepest movement of wetting front
Psychrometer installation	Following test pad construction	Monitor water potential profiles
Psychrometer monitoring	Every two weeks for the first year, then monthly thereafter	Monitor water potential profiles
Vegetation monitoring	Quarterly throughout the test period	Monitor vegetative cover and composition
Weather monitoring	Ongoing throughout the test period	Record climatological conditions
As-built soil sampling	Following test pad construction	Confirm assumed hydrological properties
As-built background bromide testing	Following test pad construction	Determine background bromide concentrations
Water content/potential sampling	Annually in early spring	Confirm psychrometer data

PERFORMANCE CRITERIA

The test pad demonstration described in the plan provides a number of clear and simple ways to determine success or failure of the test pad and, therefore, the proposed alternative final cover. This section provides the criteria for assessing the pass/fail performance of the test pad based upon the monitoring and sampling described above.

Bromide Tracer

Based upon observations made in the test pits during the on-site field investigation, little or no preferential flow is expected in the test pad profile. Bromide tracers will be used, however, to help confirm this supposition. Whereas other standard soil instrumentation, such as the thermocouple psychrometers, are practically incapable of monitoring preferential flow paths, the bromide tracer is very suitable for identifying preferential flow within the profile.

The test pad pass/fail criteria based upon the bromide tracer data are as follows:

- *Pass:* Bromide concentrations below the base of the test pad are less than twice background concentrations.

- *Fail:* Bromide concentrations in the test pad sub-base material are high (twice background concentrations or higher), providing direct evidence of wetting front movement through the cover and into the underlying sub-base soils.

- *Ambiguous:* Bromide concentrations are significant (twice background concentrations or higher) at the base of the cover and at or near background in the underlying sub-base soils. This information alone cannot be used to assess the performance of the test pad.

Soil Water Content and Water Potential

Water potential and water content data collected from monitoring the thermocouple psychrometers and laboratory measurements of selected soil samples, as described previously, can be used to assess the pass/fail performance of the test pad as follows:

- *Pass:* Measured water potential gradient within or at the base of the test pad is always upward after vegetation has established (likely after one to two years). Laboratory measurements of soil water content and potential confirm that the bottom of the test pad is still drying during the wettest time of the year. If the water potential gradient is upward, there is either no or negative flux through the test pad.

- *Pass:* Measured water potentials at the base of the test pad show corresponding unsaturated hydraulic conductivities of less than 1 x 10^{-8} cm/s at or near a unit downward hydraulic gradient.

- *Fail:* Measured water potentials at the base of the test pad exceed an equivalent flux of 1 x 10^{-8} cm/s on an annual basis.

Modeling

The water balance modeling conducted to evaluate the proposed alternative final cover indicates that the cover clearly passes the infiltration performance threshold of 1 x 10^{-8} cm/s. Additional modeling should only be conducted to refine estimated water flux through the test pad if significant ambiguity exists in the pass/fail criteria discussed above. Any additional modeling would use climate data collected from the ESII Site B weather station located adjacent to the proposed test pad (see Figure 1) and soil and vegetation data collected as part of the monitoring and sampling. The pass/fail criteria would then be as follows:

- *Pass:* Refined average annual flux estimate is less than or equal to 1 x 10^{-8} cm/s.

- *Fail:* Refined average annual flux estimate is greater than 1 x 10^{-8} cm/s.

SUMMARY AND CONCLUSIONS

In summary, for water balance and vegetative cover, water fluxes under existing vegetation at the ESII Site B are small and likely less than 1 mm/y. Soil-water potential data, long-term accumulation of calcium carbonate in surface soils, on-site observations, observations from other semiarid grassland sites, numerical modeling using UNSAT-H and HELP, and nearby research experience support the conclusion that the potential for water percolation at the site is low. Finally, this investigation has demonstrated the following:

- The proposed ET cover is equivalent to the RCRA C cover.

- Percolation for both caps and at the ESII Site B is essentially zero.

- Conservative assumptions for the water balance modeling were employed.

- Materials (soils) are available and suitable for the proposed ET cover system.

- Native vegetation and proposed naturalized vegetation will work for the proposed ET cover.

- A vegetative cover, using the appropriate plant species provides a self-perpetuating and self-repairing system for long-term percolation control. The approach also meets the additional design objectives of a low-cost, low-maintenance system.

- The proposed ET cover can be constructed effectively with standard construction procedures.

- The proposed monitoring and sampling of the test pad will provide data that allows simple, qualitative assessment of the pass/fail performance of the test pad and proposed alternative cover.

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